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REMINISCENCES OF PHYSICS AND PHYSICISTS[1]

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WHEN I, somewhat light-heartedly, accepted Sir William Bragg's invitation to give a Friday evening discourse on incidents in my memory connected with the Royal Institution, I did not realize how difficult the task would be. It was difficult to find a name for the lecture and difficult to know what to select from the many events which have occurred in the sixty years during which I have been connected with the institution or been in touch with those who were. Finally, I decided that perhaps the best thing I could do would be to choose some of the outstanding discoveries in this period and consider them in connection with the institution. Not a few of these have been made by its professors; all have been the subject of "Friday evenings" soon after they were made when they had the charm and simplicity of youth. The experiments I shall show will be those made at the time. I do not think we can realize what great achievements these discoveries were unless we take into consideration the very rough means, according to modern ideas, which had to be used to make them.

This lecture must necessarily be somewhat personal, and I hope to be excused if I take this opportunity of acknowledging the debt I owe to my first teachers in science at the Owens College, Manchester. I went to the Owens College, now the University of Manchester, through a mere accident. It was intended that I should be an engineer, and in those days the only way to do this was to be apprenticed to some big engineering firm. The firm I was to go to had a very

[1] Friday evening discourse before the Royal Institution of Great Britain.

long waiting list and told my father it would be a long time before I could be taken on. A friend to whom my father mentioned this said, "If I were you I should send him while he is waiting to the Owens College; it must be a pretty good kind of place for young John Hopkinson, who was educated there, has just come out senior wrangler." My father took this advice and I was sent to Owens when I was not fifteen years old; this was thought such a scandal that the authorities passed a resolution that in future no one under sixteen should be admitted.

In those days the college was a house in which Cobden had lived; it was by no means large and we were much cramped for space. The lectures on engineering were given in what had been the stable, and the drawing office was a converted hay loft. But though the building was so poor, few universities have had such a brilliant staff of professors. There was Balfour Stewart for physics, Roscoe for chemistry, Osborne Reynolds for engineering, Thomas Barker for mathematics, W. Crawford Williamson, the great paleo-botanist, James Bryce, who was afterwards ambassador to the United States, Adolphus Ward, the historian, who afterwards became Master of Peterhouse, and Stanley Jevons, the political economist.

The teaching at Owens College sixty-three years ago was as good as I could get anywhere if I was beginning my studies now. My first introduction to physics was the lectures of Balfour Stewart. These were so clear that, child as I was, I could understand them. He was a very interesting man with a strong metaphysical turn, and with P. G. Tait wrote a book "The Unseen Universe" which attracted a good deal of attention when it appeared. Barker, the professor of mathematics, though as far as I know he never published a paper, was as good a teacher as any one I ever came across. His methods were not altogether orthodox, since under him I learned quaternions before Cartesian geometry. I do not think this order would in general be recommended, but I think we worked the better for it, we looked upon ourselves as pioneers and felt that it was up to us to make good.

As I was taking the engineering course the professor I had most to do with in my first three years at Owens was Osborne Reynolds, who, too, forms a connection with the Royal Institution. He was one of the most original and independent of men and never did anything or expressed himself like any one else. It was difficult to take notes at his lectures, the result being that the student had to read his textbooks more diligently. In fact, it was only in his Friday evening discourses at the Royal Institution that he expressed himself so that he could be immediately understood. He was a great personality, one of his outstanding characteristics being that when he took up a problem he began to think it out for himself from the beginning. This I think is a better way than that of beginning by forming a bibliography and reading the literature. Many people's minds are more alert when they are thinking than when they are reading, and they are less apt to accept as satisfactory some plausible explanation which will not bear criticism. Osborne Reynolds did important work on the discontinuity of the motion of a fluid flowing through a pipe; a fundamental constant in this subject is called the Reynolds constant, on lubrication, on the calming of waves by rain, on the singing of a kettle and on the reason why sound traveling against the wind is not heard as well as when it travels with it. He worked out with great success the consequences which follow from the fact that a collection of equal spheres can be "piled" in different ways, and brought before the Royal Institution many beautiful illustrations of these. He worked out a theory of the universe on the assumption that it consisted of a large number of spheres in contact, and claimed that it was the one, and the only one conceivable, purely mechanical system capable of accounting for all the physical evidence as we know it.

In the early seventies the outstanding subject of interest in physics was Crookes's radiometer, or light mill, which in its commonest form consisted of a system of vanes which could rotate round a pivot supported in a cup of glass. These vanes were blackened on one side and bright on the other and when a light was brought near them they rotated, the direction of the rotation being the same as if the blackened side were repelled by the light. They aroused very general interest, and shopkeepers had them rotating in their windows to attract a crowd.

The discovery of the radiometer by Crookes was a triumph of vigilance in observation and accurate measurement. When he was engaged in making very accurate weighings to determine the atomic weight of thallium, an element which he had lately discovered, he found small discrepancies which he could not account for by any known source of error. He set himself to trace the origin of these, and by ingenious experiments convinced himself that they were due to light falling on the balance. This led him to make *ad hoc* experiments on the effect of light on delicately poised pieces of metal, and hence to the radiometer. At first the rotation was ascribed to a pressure exerted by light on the vanes; such a pressure exists, but in normal conditions the direct pressure of light is far too small to produce rotations such as those which occur in a radiometer. They turned out to be due to the blackened surfaces getting hotter than the bright ones, owing to their absorbing more light. When the molecules of the gas strike against the blackened side they get hotter and shoot off with a higher velocity than when they strike against the bright one, so that the kick or recoil is greater on the blackened surface than on the bright.

Though the radiometer did not yield anything as fundamental as had been hoped, and it may be said deserved, yet it was the means of leading Crookes to devote himself to the study of high vacua and to cathode rays. The work occupied him for many years and resulted in some of the most beautiful experiments known to physics, with which year by year he delighted audiences at the Royal Institution. These led him to a conception of a fourth state of matter, a state in which the molecules of the gas were so far apart that they could travel across the vessel in which they were contained. He said, and said quite truly, that the properties of such a gas would be quite different from those of one at ordinary pressures, when the molecules can not go more than a very small fraction of a millimeter without coming into collision with another molecule. It turned out, however, and this was first announced at a Friday evening discourse in this room, that the cathode rays were not merely molecules of the gas moving without interference from other molecules, but that they were very much smaller particles—electrons—knocked out of the molecules of the gas, and that these small particles were of the same kind from whatever kind of gas they proceeded, showing that the electron was a constituent of every kind of substance.

Towards the end of the seventies there was an outburst of researches on the passage of electricity through gases, a subject whose vital importance in connection with the structure of molecules and atoms was just beginning to be realized. Warren de la Rue and Müller, Spottiswoode, Moulton and Schuster all made important researches in this branch of physics. The experiments of de la Rue on striations in the electric discharge are of quite exceptional interest and beauty. The "Friday evening" at which he gave an account of them was on the heroic scale. The preparation of the experiment occupied, I believe, nine months. He set up in the institution, for his lecture, a battery of 14,000 cells. The tubes which I have before me on the table, and which have remained in the institution ever since the lecture more than fifty years ago, are witness of the abundance of the experiments with which the lecture was illustrated. It was rumored that he spent many hundreds of pounds on its preparation.

With the nineties began a series of discoveries following one another in quick succession, to which that much-abused term "epoch making" may be appropriately applied.

In 1891 in one of the lectures given in commemoration of the centenary of the birth of Faraday, Dewar exhibited liquid oxygen in bulk, following this first with liquid air and then with liquid hydrogen. He continued his low temperature researches for many years. Two of the discoveries he made were even greater achievements than the liquefaction of gases; one of these was the vacuum jacket, impervious to heat, called the thermos flask, but which ought to be called the Dewar flask, which has been a joy and comfort and a help to millions spread over every country in the world. The other discovery was that of producing high vacua by absorbing the gases by charcoal cooled with liquid air. Most of the discoveries in modern physics have been made by studying molecules as individuals and not as crowds. To do this we must have high vacua. Every improvement in the vacuum has resulted in new discoveries. The charcoal method gave us better vacua than we had had before and many important discoveries could not have been made without it.

In 1894 argon was discovered by Lord Rayleigh whom both the Royal Institution and the Cavendish Laboratory can claim as one of their professors. This discovery is one of the romances of science; it has been described more prosaically as the triumph of the third place of decimals. It was due to Lord Rayleigh finding that the weight of the gas in a vessel was 2.31 gm when the vessel was filled with nitrogen obtained from the air, while it was only 2.30 gm when it was filled with nitrogen obtained from chemical compounds of nitrogen. This difference, less than one half of one per cent., led, in the hands of Lord Rayleigh and Sir William Ramsay, to the discovery of the new element argon. It is a striking example of the way accurate measurement may lead to most fundamental discoveries. It seems hardly possible, however, that any discovery would lead to more startling results than this, for it was found that more than 1 per cent. by weight of the atmosphere consisted of argon, so that there are pounds of it in a fair-sized room and hundredweights in most chemical laboratories. Moreover, the discovery was not made by using some new-fangled physical apparatus of which chemists are so shy, but by the balances which abound in every chemical laboratory and in the use of which chemists are expert. No wonder the chemists were incredulous; they could not believe that with their delicate methods, by which they can detect fractions of a milligram of most substances, they could have missed pounds of argon. It is the most wonderful case on record of a successful attempt at escape from detection, and succeeded because argon, so to speak, kept itself to itself, and would form no alliances with the most attractive brides offered to it by the chemist. But though argon had taken the measure of Scotland

Yard it had forgotten Sherlock Holmes and when he took a hand the game was up. Besides the discovery of argon, 1894 was memorable for Hertz's discovery of electric waves. The "Friday evening" given by Sir Oliver Lodge on this discovery was one of the most outstanding in the long roll of these discourses. The next year marked the discovery of Röntgen rays. It would, I think, be a striking example of the importance of research in pure physics in promoting employment, if we had the figure for the number of people in this country employed in the industries created by the discoveries made in the decade 1890–1900; the number of people employed in the manufacture of thermos flasks, in broadcasting, in the manufacture of the instruments used for wireless and for the medical applications of Röntgen rays.

This lecture is on reminiscences connected with the Royal Institution, so that accounts of quite recent discoveries would not be within its scope. There is one subject, however, which is now attracting a good deal of attention—heavy hydrogen—which satisfies both conditions; it is a reminiscence and it is connected with the Royal Institution. In 1911 I gave a Friday evening discourse "On a New Method of Chemical Analysis."[2] By this method each kind of gaseous particle in a vessel through which an electric discharge is passing produces its own parabolic curve on a photographic plate. Thus if the vessel contained a mixture of hydrogen, oxygen and nitrogen there would be six parabolas corresponding to the atoms and molecules of hydrogen, oxygen and nitrogen, respectively, along with others due to each of the compounds formed by these elements. The mass of the particle which produces any parabola can be determined from the position of the parabola.

Using this method, I detected the presence of a parabola which must have been produced by a particle of mass 3 (the mass of the hydrogen atom being taken as the unit). I obtained it first when the gas in the discharge tube was hydrogen prepared in the ordinary way, but its appearance was very capricious, and only occurred in a small percentage of the experiments. I found, however, that if, instead of using ordinary hydrogen, I used the gases given off by certain solids when bombarded with cathode rays, the (3) parabola appeared with great regularity. The amount of the gas producing it varied with the nature of the solid bombarded, but there were few minerals or salts among those I tried which did not give traces of it; potash (KOH) is a very convenient source, and a specimen of black mica given to me by Sir James Dewar gave an exceptionally large supply.

I obtained the active gas also by deflagrating a very thin wire by passing a very large current through it, or even by raising a wire to bright incandescence. This indicates that the bombardment by the cathode rays does not manufacture the gas but merely liberates it from the solid.

I made a very large number of experiments on the gas obtained in this way, the results of which were published in the *Philosophical Magazine* and summarized in my book, "Rays of Positive Electricity" (Longmans). One important property of this gas was that it could be stored after bombardment and tested long after it had been produced, showing that it is a stable gas and can exist in an uncharged state. In fact, the persistence with which it clung to the walls of the discharge tube and the cathode made experiments troublesome, as once the tube had been used for this gas, it would continue to show the (3) parabola after the gas had been pumped out and replaced by another of a different kind; long sparking with oxygen in the tube is required to get rid of it.

I made many tests of the chemical properties of this gas and found that under them it behaved like ordinary molecular hydrogen. Thus, for example, it disappeared after vigorous sparking in the presence of oxygen, or when passed slowly over red hot copper oxide; again like hydrogen it can pass through red hot palladium; and there was evidence that when an electric discharge was passed through it, some of its molecules were split up into a positively charged hydrogen molecule and a negatively charged hydrogen atom.

Through the kindness of Lord Rutherford, I have had the opportunity of examining by the positive ray method samples of 80 per cent. concentration of heavy hydrogen prepared by recent methods. Very interesting photographs obtained with heavy hydrogen of less concentration have been published by Professor P. Zeeman. So far as I can see, the heavy hydrogen behaves in just the same way as the form of hydrogen obtained by bombarding solids. With these high concentrations, so much heavy hydrogen adheres to the walls of the tube that instead of trying to get rid of it by bombarding with oxygen, it saves time to make a new tube for each experiment. Again, with the highly concentrated gas, I found, as Professor Zeeman had done, parabolas corresponding to H_4 and H_5; in my early experiments a parabola (4) was frequently seen along with H_3. I ascribed it to helium and probably some of it was due to this source, but now I think part of it may have been due to H_4; on a few occasions, too, I observed a line corresponding to H_5. The evidence seems to me to leave little doubt that the gas I called H_3 more than twenty years ago is the same as that which is now called heavy hydrogen.

I said in "Rays of Positive Electricity" that from

[2] *Proc. Roy. Inst.*, Vol. XX, p. 140.

my experiments I suspected that there might be two kinds of H_3; this surmise is confirmed by the fact that many chemists who have experimented on triatomic hydrogen have come to the conclusion that it has a life of only a minute or so, and can only exist when charged with electricity. So far as I know, they all used hydrogen prepared in the usual way and not that obtained by bombarding solids; there is not the slightest doubt that the H_3 obtained in the latter way is stable and can exist uncharged.

I think the effect of the solid is due to its adsorbing a mixture of gases including H_2 and H_3, and that when it is bombarded, relatively more H_3 than H_2 comes off from the adsorbed layers. Thus the mixture that comes out is richer in H_3 than the mixture in the gas adsorbed by the solid.

ROCK FORMATIONS OF DEATH VALLEY, CALIFORNIA[1]

By Dr. L. F. NOBLE

U. S. GEOLOGICAL SURVEY

Preliminary Statement

During the past two years the Geological Survey has been making a study of the geology of Death Valley. The area under investigation includes all Death Valley south of parallel 117° 30′ (which crosses Death Valley four miles north of the Furnace Creek Ranch) and enough of the neighboring territory to provide evidence necessary for an understanding of the general stratigraphic and structural relations of the region. The area is included in the northern half of the Avawatz Mountains topographic map and the southern half of the Furnace Creek topographic map and adjoins on the south the area described and mapped by Ball,[2] whose work covered all the region north of parallel 117° 30′. The investigation, which is designed to attain the scope of a fairly thorough geologic reconnaissance, is being carried out by the writer. Two winter seasons of field work have been completed with the aid of a mosaic of air photographs taken specially for the project. During a part of the first season the writer was assisted by C. L. Gazin.

At the time when the investigation was begun little was definitely known concerning the age, character and distribution of the rocks in the area and almost nothing concerning the structure. The first step in the investigation therefore was to determine the age and sequence of the rocks, without which knowledge it is impossible to decipher the structure. The field work thus far has been devoted to obtaining this fundamental knowledge. It remains to work out the structure and to supplement the stratigraphic reconnaissance by a more detailed study of some of the rock formations.

In the statement which follows no attempt is made to describe the rocks systematically or in detail. For example, the term granite is used for rocks that range in composition from granite to quartz diorite, and the term limestone is used for both limestone and dolomite. Thicknesses given for formations are only rough estimates, because few detailed sections have been measured. Lists of fossils found in the Paleozoic strata and the reports on these fossils made by Survey paleontologists will be reserved for another paper.

Age and Character of the Rocks

The Death Valley area contains rocks of all the great geologic time divisions—Archean, Algonkian, Paleozoic, Mesozoic, Tertiary and Quaternary—whose aggregate thickness certainly exceeds 30,000 feet for the stratified rocks alone, but earth movements in the area have been so profound and so recurrent that the rock masses form a complex mosaic of crustal blocks isolated one from another by folding, faulting, tilting, igneous intrusion, erosion and burial under Quaternary alluvium. Consequently, the sequence is not complete at any one locality and can be pieced together only by examining many different parts of the area.

PRE-CAMBRIAN ROCKS

Archean rocks.—The rocks of the oldest system, the Archean, are the basal rocks of the region. They are chiefly gneisses and mica schists but include bodies of quartzite and limestone. A common type of gneiss is remarkably coarse and granitic and contains conspicuous large crystals of pink feldspar. Another common type is a dark gray dioritic gneiss or metadiorite. All the Archean rocks have been recrystallized by heat and pressure and contain no recognizable traces of life. In origin they are in part igneous and in part sedimentary. As a whole they greatly resemble the Archean rocks that make the Granite Gorge in the bottom of the Grand Canyon. Like the Grand Canyon Archean rocks they are separated from an

[1] Published by permission of the Director, U. S. Geological Survey.

[2] S. H. Ball, "A Geologic Reconnaissance in Southwestern Nevada and Eastern California," *Bull. U. S. Geol. Surv.*, 308, 1907.